

***W*-boson transverse momentum distributions**

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- Partonic channels
- NLO corrections
- Soft-gluon corrections at two loops
- NNLL resummation and expansions
- Approximate NNLO p_T distribution at LHC

In collaboration with R. J. Gonsalves

W production at large p_T - parton processes

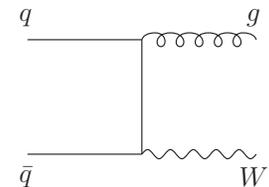
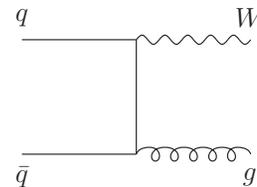
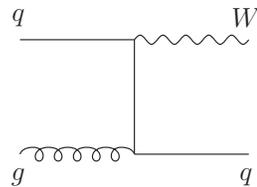
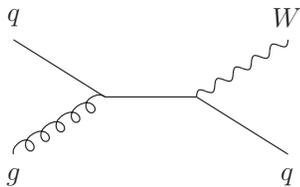
W hadroproduction useful in testing the SM and in estimates of backgrounds to Higgs production and new physics (new gauge bosons)

p_T distribution falls rapidly as p_T increases

Partonic channels at LO

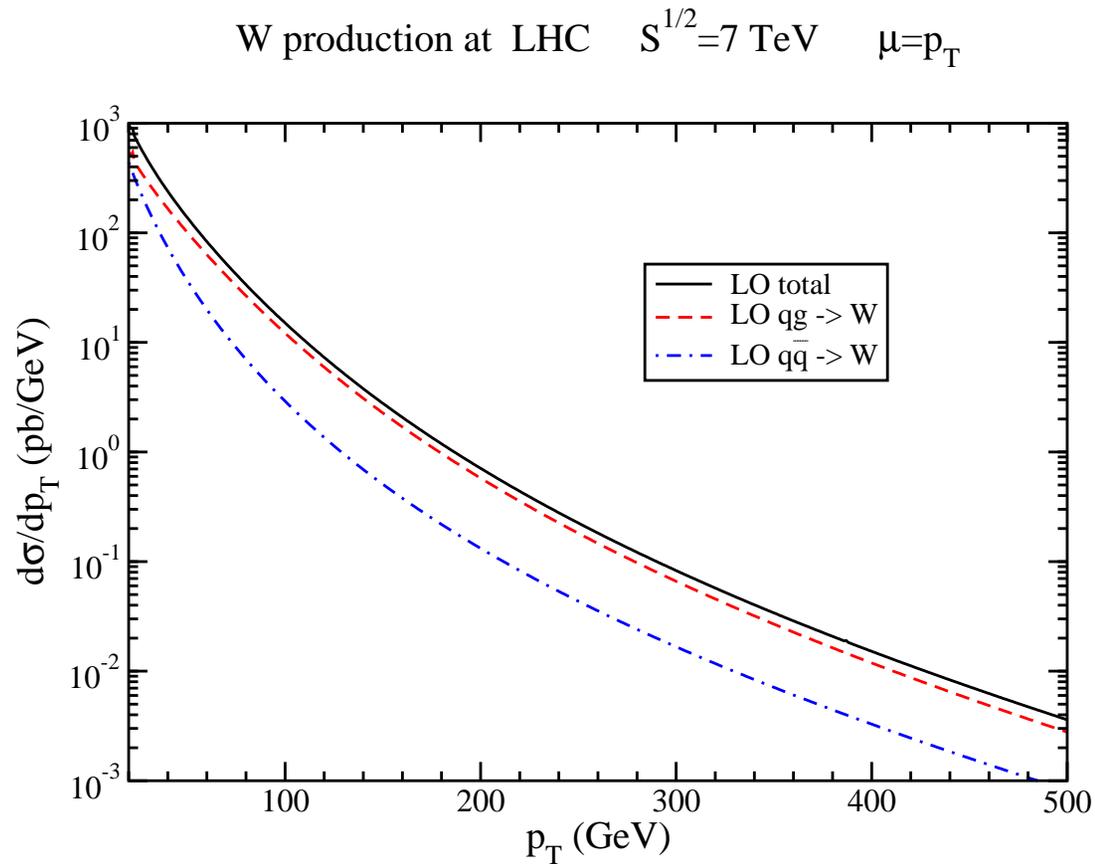
$$q(p_a) + g(p_b) \longrightarrow W(Q) + q(p_c)$$

$$q(p_a) + \bar{q}(p_b) \longrightarrow W(Q) + g(p_c)$$



Define $s = (p_a + p_b)^2$, $t = (p_a - Q)^2$, $u = (p_b - Q)^2$ **and** $s_4 = s + t + u - Q^2$

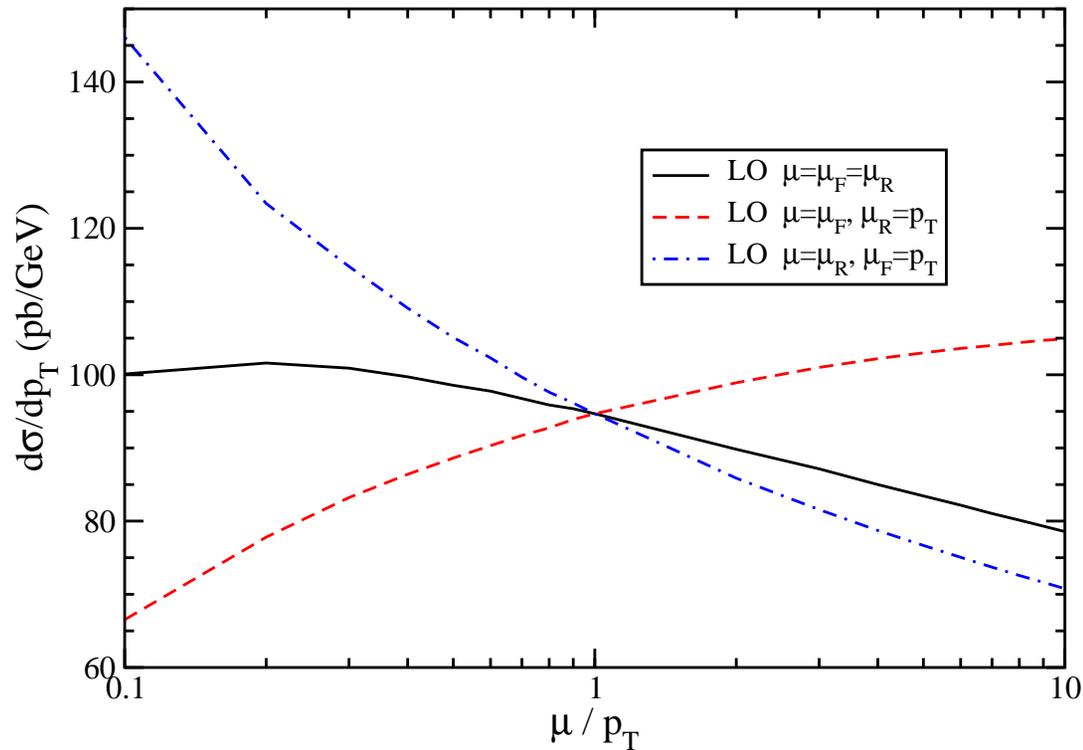
Leading-order results for W production at the LHC



qg channel is numerically dominant

LO scale dependence for W production at the LHC

W production at LHC $S^{1/2}=14$ TeV $p_T=80$ GeV



At LO μ_F and μ_R dependence largely cancel each other

NLO corrections

The NLO cross section can be written as

$$E_Q \frac{d\hat{\sigma}_{f_a f_b \rightarrow W(Q)+X}}{d^3Q} = \delta(s_4) \alpha_s(\mu_R^2) [A(s, t, u) + \alpha_s(\mu_R^2) B(s, t, u, \mu_R)] + \alpha_s^2(\mu_R^2) C(s, t, u, s_4, \mu_F)$$

The coefficient functions A , B , and C depend on the parton flavors

The coefficient $A(s, t, u)$ arises from the LO processes

$B(s, t, u, \mu_R)$ is the sum of virtual corrections and of singular terms $\sim \delta(s_4)$ in the real radiative corrections

$C(s, t, u, s_4, \mu_F)$ is from real emission processes away from $s_4 = 0$

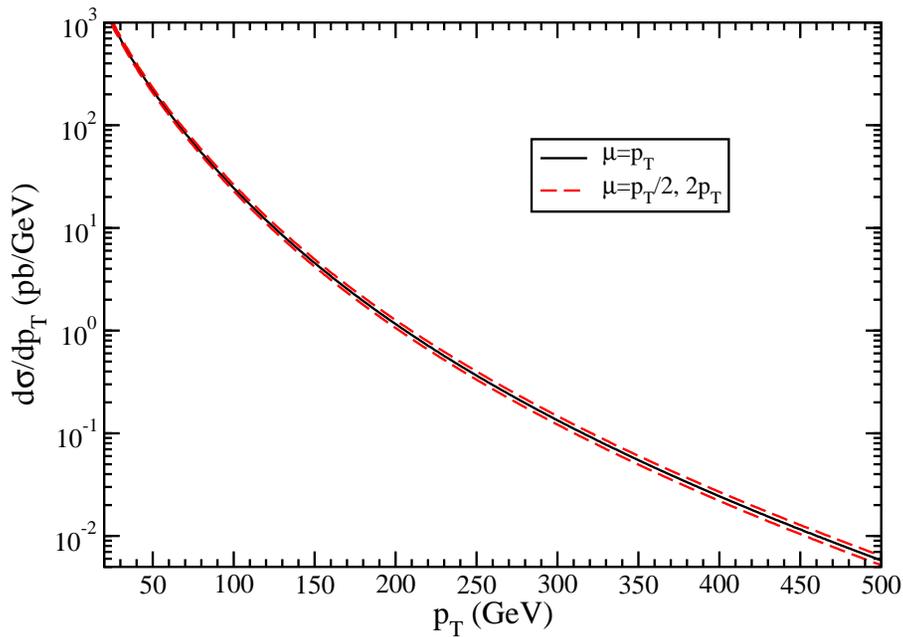
P.B. Arnold and M.H. Reno, Nucl. Phys. B 319, 37 (1989); (E) B 330, 284 (1990)

R.J. Gonsalves, J. Pawlowski, C.-F. Wai, Phys. Rev. D 40, 2245 (1989);

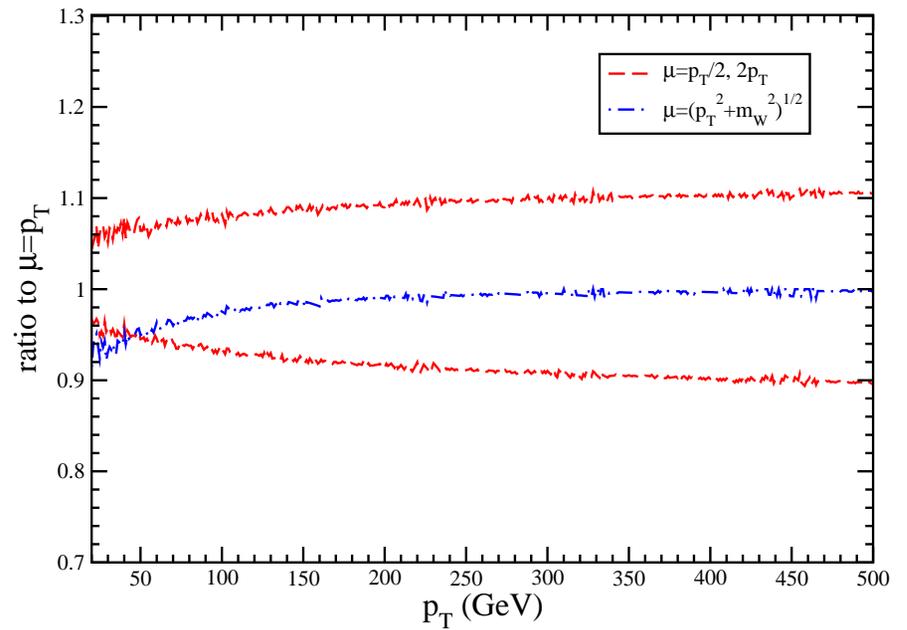
Phys. Lett. B 252, 663 (1990)

NLO p_T distribution of the W -boson at the LHC - 7 TeV

W production at LHC NLO $S^{1/2}=7$ TeV

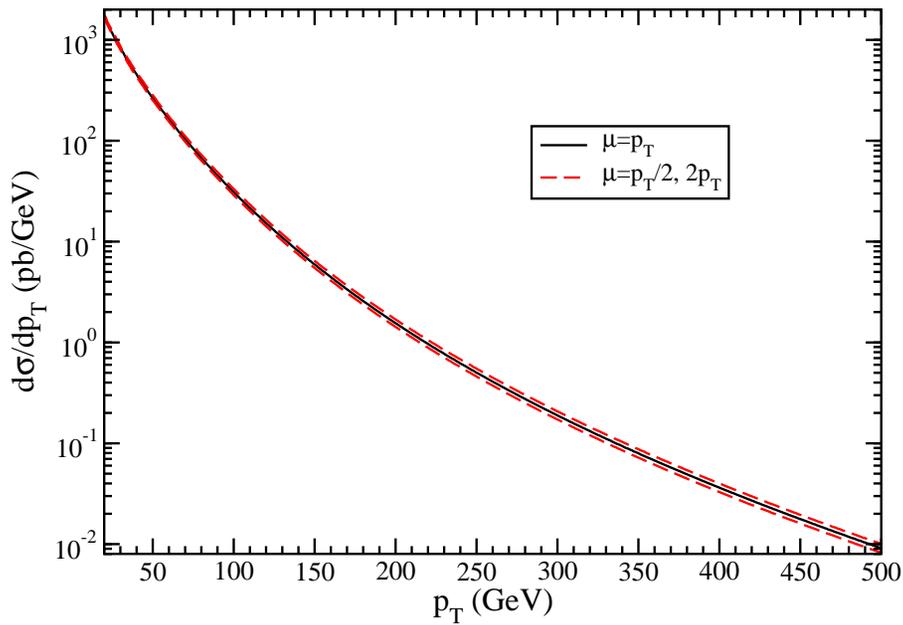


W production at LHC NLO $S^{1/2}=7$ TeV

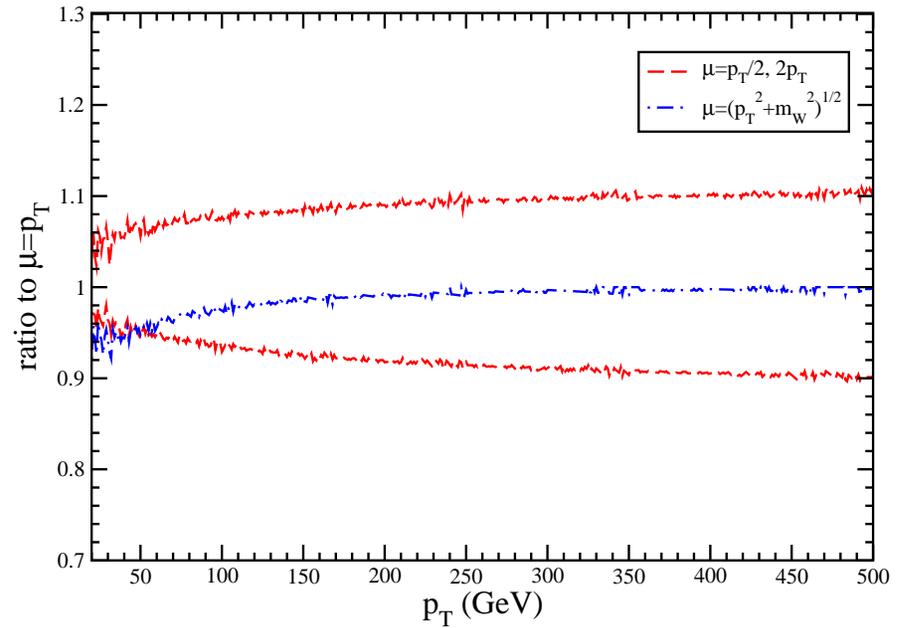


NLO p_T distribution of the W -boson at the LHC - 8 TeV

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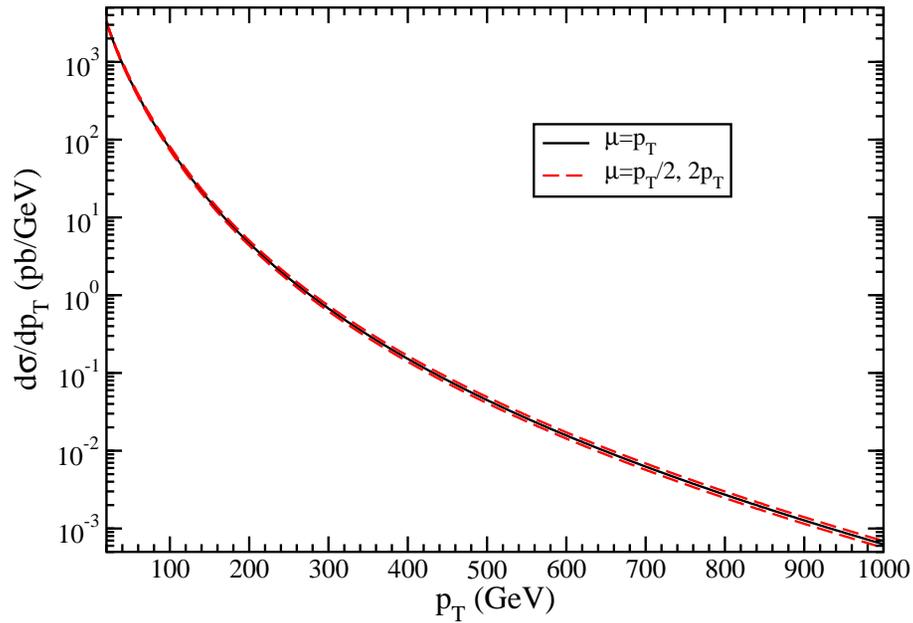


W production at LHC NLO $S^{1/2}=8$ TeV

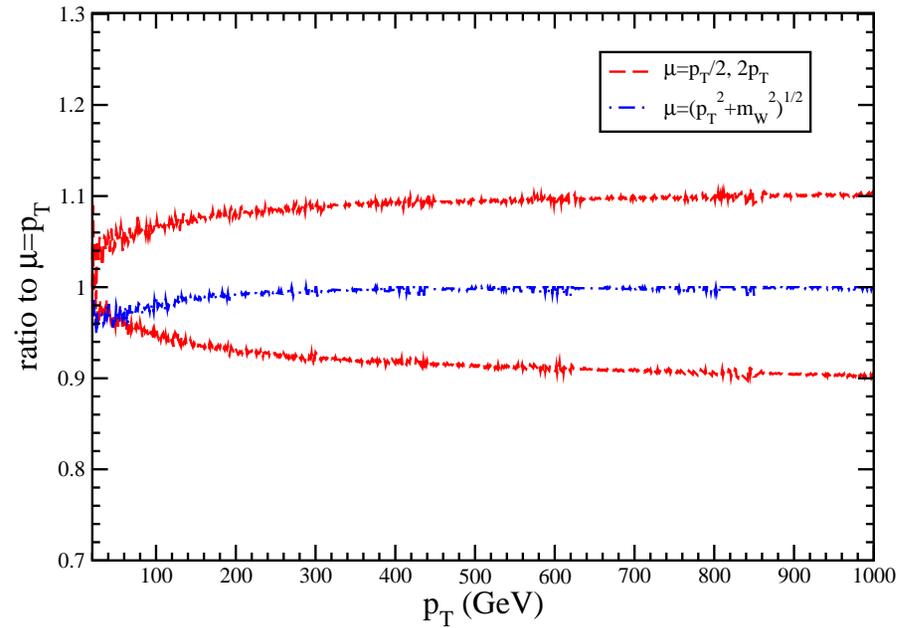


NLO p_T distribution of the W -boson at the LHC - 14 TeV

W production at LHC NLO $S^{1/2}=14$ TeV



W production at LHC NLO $S^{1/2}=14$ TeV



Soft-gluon corrections

At partonic threshold $s_4 \rightarrow 0$

Soft corrections $\mathcal{D}_l(s_4) \equiv \left[\frac{\ln^l(s_4/p_T^2)}{s_4} \right]_+$

For the order α_s^n corrections $l \leq 2n - 1$

At NLO, $\mathcal{D}_1(s_4)$ and $\mathcal{D}_0(s_4)$ terms

At NNLO, $\mathcal{D}_3(s_4)$, $\mathcal{D}_2(s_4)$, $\mathcal{D}_1(s_4)$, and $\mathcal{D}_0(s_4)$ terms

We can formally resum these logarithms to all orders in α_s

New two-loop results: $\mathcal{D}_0(s_4)$ terms now fully determined

New approximate NNLO from NNLL resummation:

N. Kidonakis and R.J. Gonsalves, Phys. Rev. D **87**, 014001 (2013)

Soft-Gluon Resummation

Resummation follows from factorization properties of the cross section
- performed in moment space

Resummed cross section

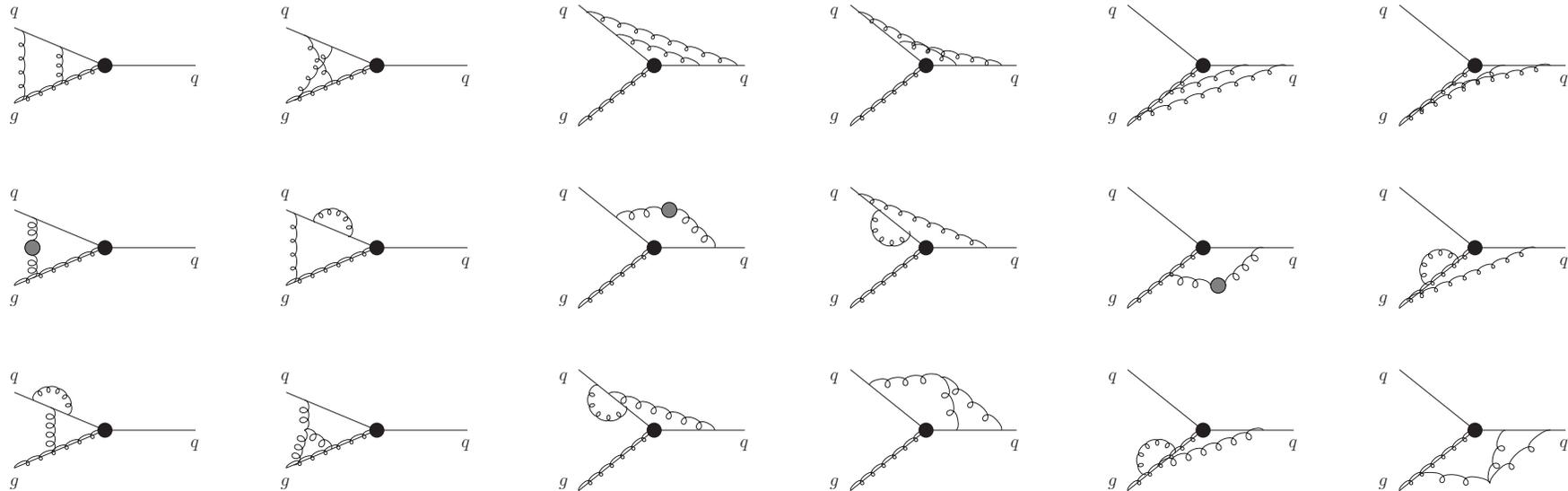
$$\hat{\sigma}^{res}(N) = \exp \left[\sum_i E_i(N_i) \right] \exp [E'_j(N')] \exp \left[\sum_{i=1,2} 2 \int_{\mu_F}^{\sqrt{s}} \frac{d\mu}{\mu} \gamma_{i/i}(\tilde{N}_i, \alpha_s(\mu)) \right] \\ \times H(\alpha_s) S \left(\alpha_s \left(\frac{\sqrt{s}}{\tilde{N}'} \right) \right) \exp \left[\int_{\sqrt{s}}^{\sqrt{s}/\tilde{N}'} \frac{d\mu}{\mu} 2 \text{Re} \Gamma_S(\alpha_s(\mu)) \right]$$

Γ_S is the soft anomalous dimension

$$\Gamma_S = \frac{\alpha_s}{\pi} \Gamma_S^{(1)} + \frac{\alpha_s^2}{\pi^2} \Gamma_S^{(2)} + \dots$$

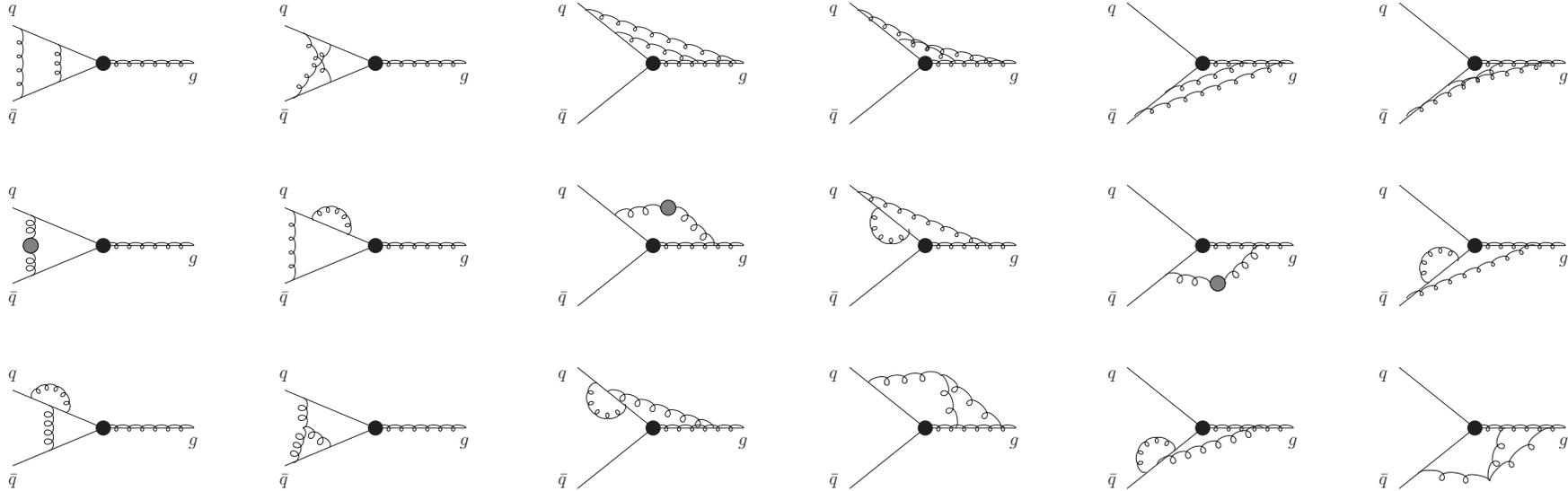
Two-loop soft anomalous dimension

Two-loop eikonal diagrams for $qg \rightarrow Wq$



Determine $\Gamma_S^{(2)}$ from UV poles of two-loop dimensionally regularized integrals

Two-loop eikonal diagrams for $q\bar{q} \rightarrow Wg$



Determine $\Gamma_S^{(2)}$ from UV poles of two-loop dimensionally regularized integrals

Two-loop soft anomalous dimension

For $qg \rightarrow Wq$ or $qg \rightarrow Zq$

$$\Gamma_{S, qg \rightarrow Wq}^{(1)} = C_F \ln \left(\frac{-u}{s} \right) + \frac{C_A}{2} \ln \left(\frac{t}{u} \right)$$

$$\Gamma_{S, qg \rightarrow Wq}^{(2)} = \frac{K}{2} \Gamma_{S, qg \rightarrow Wq}^{(1)}$$

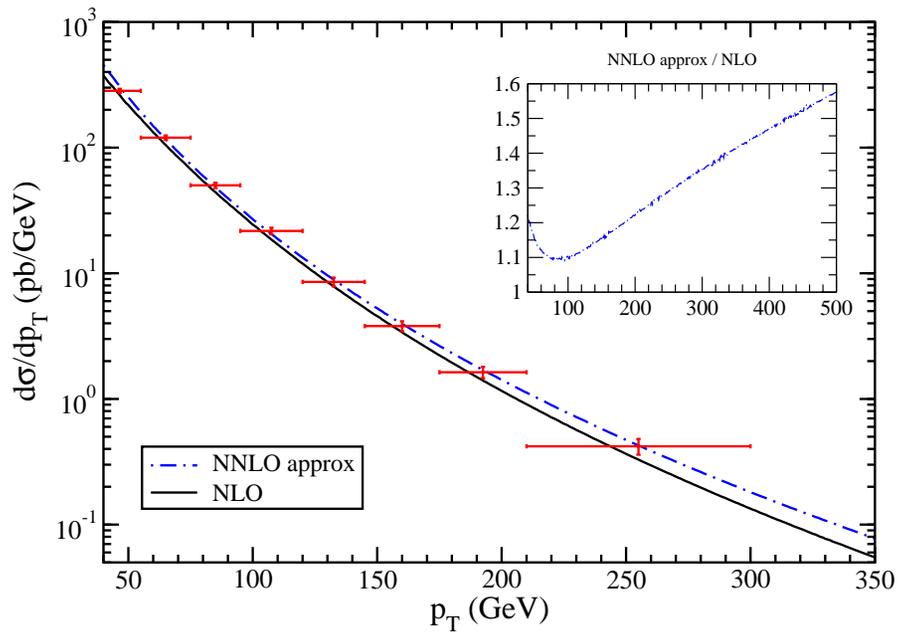
For $q\bar{q} \rightarrow Wg$ or $q\bar{q} \rightarrow Zg$

$$\Gamma_{S, q\bar{q} \rightarrow Wg}^{(1)} = \frac{C_A}{2} \ln \left(\frac{tu}{s^2} \right)$$

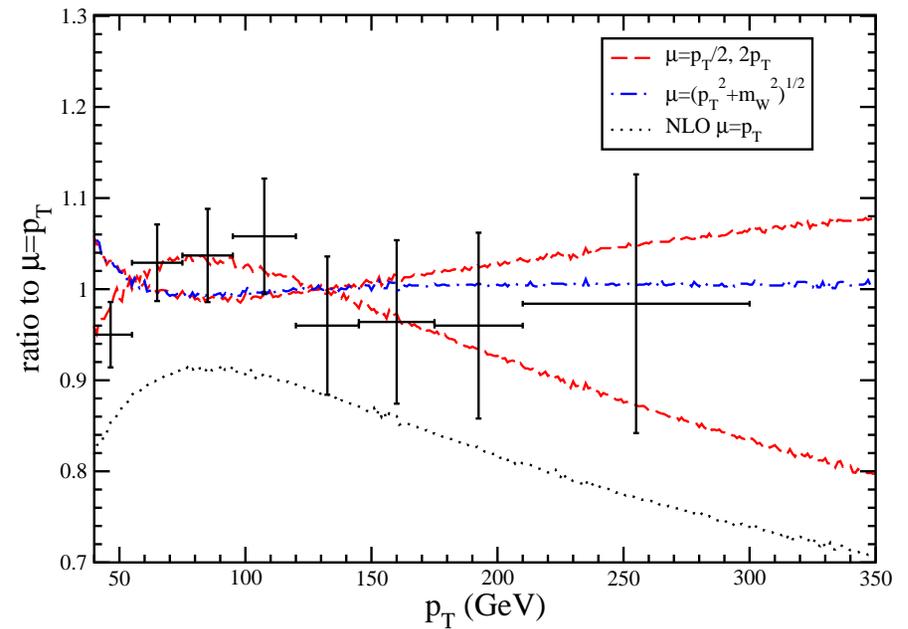
$$\Gamma_{S, q\bar{q} \rightarrow Wg}^{(2)} = \frac{K}{2} \Gamma_{S, q\bar{q} \rightarrow Wg}^{(1)}$$

NNLO approx for W production at the LHC at 7 TeV

W-boson p_T distribution at LHC $S^{1/2}=7$ TeV $\mu=p_T$



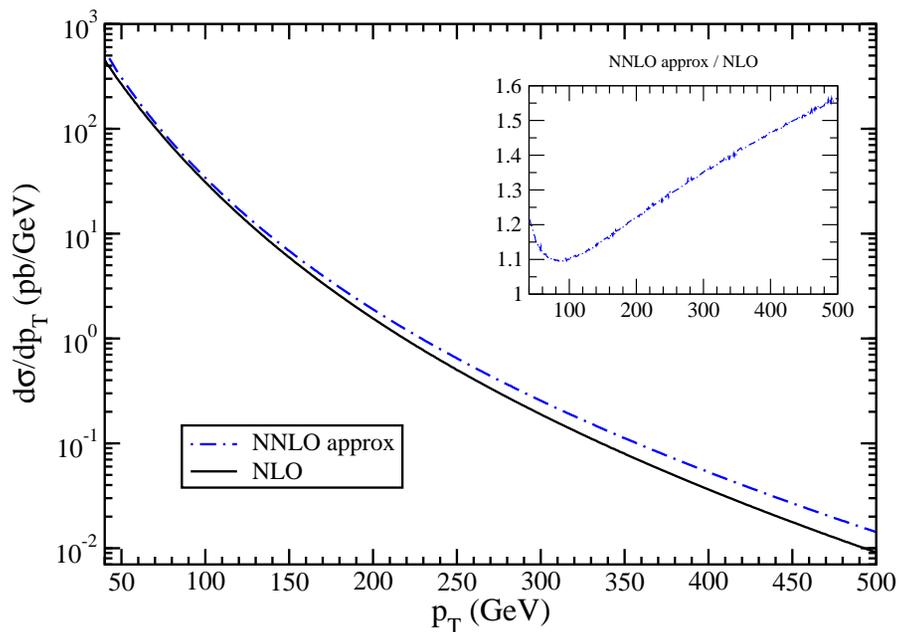
W production at LHC NNLO approx $S^{1/2}=7$ TeV



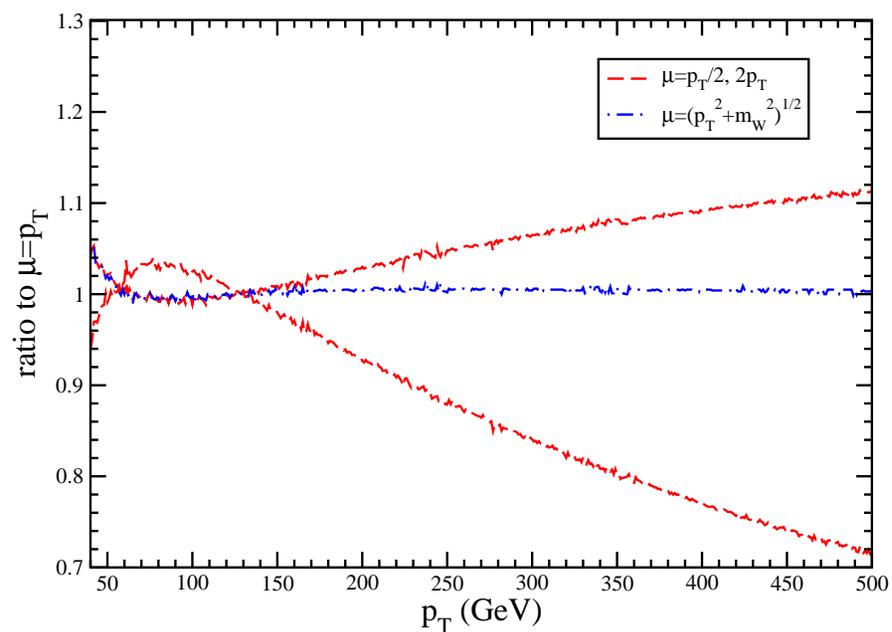
with MSTW 2008 pdf

NNLO approx for W production at the LHC at 8 TeV

W-boson p_T distribution at LHC $S^{1/2}=8$ TeV $\mu=p_T$

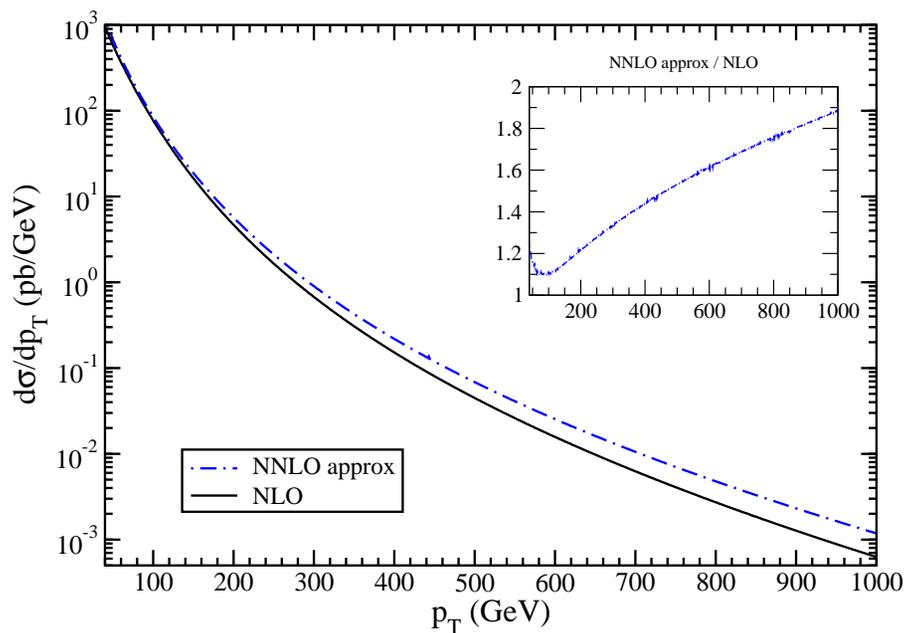


W production at LHC NNLO approx $S^{1/2}=8$ TeV

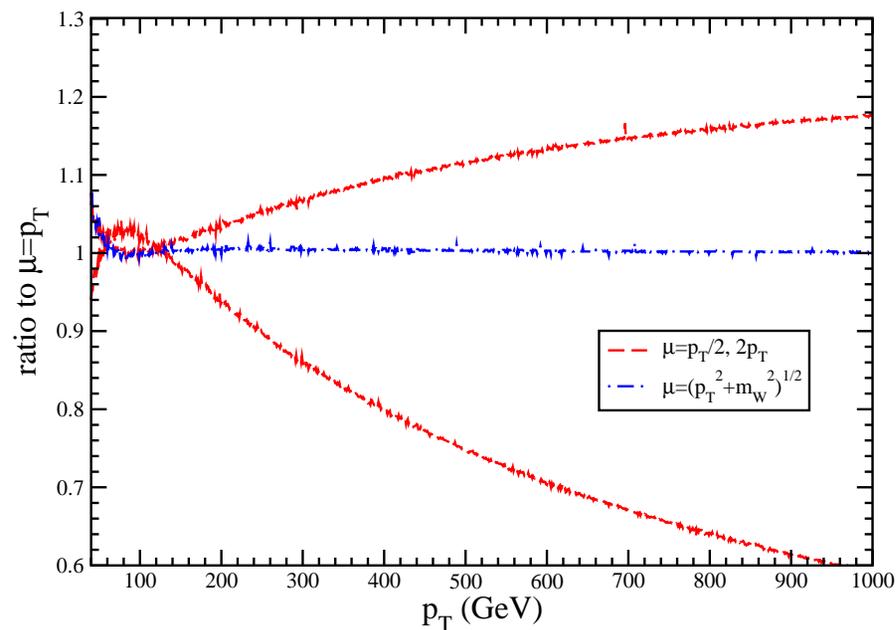


NNLO approx for W production at the LHC at 14 TeV

W-boson p_T distribution at LHC $S^{1/2}=14$ TeV $\mu=p_T$



W production at LHC NNLO approx $S^{1/2}=14$ TeV



Summary

- W production at large p_T at the LHC
- NLO results
- Soft-gluon two-loop threshold corrections
- NNLL resummation
- NNLO soft-gluon corrections have been calculated
- Large NNLO soft corrections
- Future work for Z production